

Appendix B

Sampling Strategies for Timber Inventory

This appendix summarises the following common forest inventory sampling techniques:

1. Selective sampling;
2. Simple random sampling;
3. Systematic sampling;
4. Stratified sampling;
5. Multi-stage sampling (combinations of 1 to 4); and
6. Multi-phase sampling (combinations of 1 to 4).

B.1 Selective Sampling

Selective sampling involves choosing samples according to the subjective judgement of the observer. A set of rules may provide a guide to what kind of sample should be selected (Husch *et al.* 1972). Selective sampling had been widely used in forestry before the advent of statistically sound sampling procedures (Shiver and Borders 1996). The method often involves the inventory team selecting areas that appear representative of the average stand condition. If the inventory team is good at selecting average stands, sound estimates can be produced. However, human choice is often prejudiced with the result that estimates are likely to be biased. There is no valid measure of variance and therefore confidence intervals cannot be calculated. This is because sampled areas were selected on account of them appearing to be average and, therefore, their variability will be less than the true variability of the whole stand (Shiver and Borders 1996).

B.2 Simple Random Sampling

Simple random sampling (SRS) is the fundamental selection method and all other statistically sound sampling methods are modifications intended to achieve greater economy or precision (Husch *et al.* 1972). In SRS, there is no subjectivity as samples

are chosen completely at random with each potential sampling unit having an equal chance of selection, completely independent of the selection of all other units. SRS yields unbiased estimates of population means and totals; however, does have several disadvantages (Husch *et al.* 1972):

- a system to randomly select plot sites within the population of interest is required, which can be non-trivial;
- establishing the bearings and distances to random sample plots and then navigating to each of them in the field can be time consuming; and
- a chance of obtaining a non-representative sample, for example, plots clustered in a patch of high quality forest that only comprises a small proportion of the total forest.

In its purest form, SRS is rarely used in forestry (Shiver and Borders 1996).

B.3 Systematic Sampling

Systematic sampling is often the method of choice in timber inventories. Sampling units are located in a predictable, systematic pattern rather than being located randomly. Systematic sampling generally involves a grid being laid over maps of the forest to be inventoried, which is perpendicular to the prevailing topographic features as much as possible (Shiver and Borders 1996). The aim is to distribute the plots over the forest so that the proportion of plots falling in a given stand type within the forest is representative of that stand type. If the sample size has been determined and the forest area is known, then the distance between grid lines and between plots on a given grid line can be determined to achieve the desired sample size. Often the start point is chosen at random and the remainder of the plots are then determined by the start point. Sometimes the start point is chosen subjectively at some easily accessible location with the assumption that any bias in the resulting estimates will be negligible (Husch *et al.* 1972).

Systematic sampling is less time consuming and more cost efficient than simple random sampling. It ensures plots are distributed throughout the forest. Husch (1972) asserted that the larger the forest area being inventoried, the greater the likelihood that a systematic sample will provide a more precise estimate than a SRS. Since plots are not

chosen at random, it is not possible to estimate the sample error of a systematic sample. A number of methods developed to approximate the sampling error associated with systematic sampling are described by Husch (1972). However, Scheaffer *et al.* (1990, cited in Shiver and Borders 1996), showed that SRS estimators of variance serve as valid estimates of the variance of systematic sampling, so long as populations do not exhibit a systematic or periodic variation from place to place in proportion to the distance between sampling units (Husch *et al.* 1972; Shiver and Borders 1996).

B.4 Stratified Sampling

Random or systematic location of inventory plots over an entire area is efficient when the area is relatively uniform in species composition, age and site quality. However, if this is not the case, then stratified sampling can be a more efficient sampling strategy (Shiver and Borders 1996). Stratification is the process of partitioning the forest into relatively homogenous classes. The effect is that population estimates can be generated with smaller standard errors than if the whole area had been sampled as one stratum. This can reduce the number of plots required to obtain an estimate of the parameter of interest within the desirable allowable error range (Parkes 1998). Once a forest is stratified, simple random sampling or systematic sampling is used to sample within each stratum. In addition to an overall estimate for the whole population, separate estimates are obtained for each stratum.

Stratification is statistically most powerful when strata are delineated according to the parameter of interest. Thus, for timber inventories, forests are often stratified according to timber production potential or *site quality*. However, this is often difficult to measure directly, so, in practice, forest attributes that tend to have a strong relationship with timber production potential are used. In timber plantations, the relationship between age of the stand and some measure of stand height is commonly used and called *site index* (Husch *et al.* 1972). The site index concept does not work well in uneven-aged forests, as height growth is not related to age, but varying stand conditions. In natural forests, stands are often stratified according to one or several forest attributes, including canopy species composition, understorey species composition, soil type, canopy height, management history and land tenure.

The simplest way to allocate plots to each stratum is to allocate plots equally to all strata; however, this is almost never employed in practice (Shiver and Borders 1996). In general, it can be expected that variability of the parameter of interest in a forest inventory will increase with the area of the stratum (Cant 1997). When this is true, allocation of plots between strata in proportion to the area they each cover will lead to a smaller total sample size for a desired allowable error than equal allocation. This is the plot allocation method used by Queensland's Department of Primary Industries – Forestry and Department of Natural Resources (Cant 1997; Eyre *et al.* 2000). The proportional allocation method assumes the variation among sampling units within each stratum is the same. If variability within each stratum is known to differ between strata, the *Neyman* plot allocation system, which accounts for different variability and stratum size is more appropriate (Shiver and Borders 1996). Cost of plot establishment may also be considered when efficiently allocating plots. For example, it may take twice as long to complete a plot in a forest with a dense shrubby understorey than in a forest with a grassy understorey. The *Optimal* plot allocation system is a system based on stratum size, variability and cost of plot establishment (Shiver and Borders 1996).

B.5 Multi-stage Sampling

In multi-stage sampling, a population can be thought of as consisting of a list of sampling units (primary stage), each of which comprises smaller units (second stage), which in turn could be made up of still smaller units (third and successive stages). A random sample could be made of the primary stage sample units, followed by a random sample of second stage sample units within each selected primary unit. This procedure is continued to the desired stage. Two-stage sampling is the most commonly applied form of multi-stage sampling (Husch *et al.* 1972). Two examples of two-stage sampling are inventory designs with plots located along randomly chosen lines or strips, and clusters of plots or point-samples at randomly chosen locations.

Multi-stage sampling is particularly useful where the primary stage samples vary in importance (*e.g.* contribution to total merchantable volume), and selection can be made with a probability proportional to their importance. An advantage of a particular form of multi-stage sampling, called *cluster sampling*, is that the field measurement work can be concentrated close to the locations of primary sampling units rather than spreading them

over the forest. This is of particular relevance when it is difficult and costly to locate primary sampling units (Husch *et al.* 1972). Husch *et al.* (1972) asserted that multi-stage sampling frequently yields estimates of a required precision at lower cost than mono-stage sampling.

Since only a subset of forest stands are inventoried, the final estimate may be more variable than if an adequate inventory was performed throughout the forest (Shiver and Borders 1996). However, for large forests where it is not possible to adequately sample each stand, multi-stage sampling, which provides sound information on a sample of stands, seems more reasonable than gathering low quality information about all stands in the forest. Sampling error can be minimised by stratifying the forest before conducting a multi-stage sample within each stratum (Shiver and Borders 1996).

To facilitate calculation of unbiased estimates of means and standard errors, random selection of sampling units at all stages should be employed, although selecting primary units with probability proportional to size is permissible (Husch *et al.* 1972). Systematic selection in multi-stage sampling is common for sampling units beyond the primary stage, *e.g.* clusters of plots in a fixed pattern around a randomly located primary unit location. Fixed clusters of this type do not permit a valid measure of within cluster variation and the entire cluster is considered as the sampling unit (Husch *et al.* 1972).

B.6 Multi-phase Sampling

In multi-phase sampling, some of the same sampling units are (usually) employed at the different phases of sampling, in contrast to the descending hierarchy of sampling units formed in multi-stage sampling. Non-biased variances can be estimated when the sample units in each phase are selected randomly, systematically or with probability proportional to size. Different formulae are available for variance estimation according to whether successive sampling phases are dependent or independent of each other (Shiver and Borders 1996). A common multi-phase sampling procedure involves the combination of aerial photograph interpretation (API) and field plots. The first phase may involve API classification of forest and non-forest. Provided appropriate photo-interpretation and measurement techniques are available, a large and relatively inexpensive subsample of relatively detailed photointerpretation plots (second phase)

can be selected from the first phase. A small subsample of the second phase plots can then be selected for relatively expensive field measurements. A regression is then fitted between the field plot volumes and the photo plot volumes, permitting a corrected volume estimate to be made for the photo plots (Husch *et al.* 1972).

In two-phase or *double sampling*, a special case of multi-phase sampling, the aim is to estimate one variable (principal variable) by utilising its relationship with another (secondary variable). This method is of most interest when information about the principal variable is costly and difficult to obtain, but the secondary and related variable can be more easily observed (Husch *et al.* 1972). Since most of the resources in double sampling are usually expended upon collecting information about the secondary variable, double sampling should only be used when the gain in precision more than compensates for the loss of precision due to reducing the sample of the variable of interest (Shiver and Borders 1996). A common double sampling procedure in forest inventory is to take advantage of the high correlation between basal area of merchantable stems (easily measured) and timber volume (difficult to measure). A large number of point-samples are made in the forest where *in* trees are only counted, not measured. For a subsample of these points, all *in* trees are measured for volume determination. Average volume per hectare and its standard error can then be estimated (Shiver and Borders 1996). However, when volume by product type is required, it is also necessary to record the product type for each tree in the count only point-samples. This markedly increases the time necessary to conduct the multi-phase technique, and the advantages of the technique may not be so pronounced. Also, the correlation coefficient between basal area and timber volume by product type is usually not as high as it is between basal area and total timber volume (Shiver and Borders 1996).

B.7 References

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Appendix C

Plot Types for Timber Inventory

This appendix describes two plot types for timber inventory: fixed and variable area plots. The latter have become increasingly popular for timber inventories in Australia and elsewhere due to the perceived savings in field time and the efficiency it offers by sampling with probability proportional to size of the tree, rather than frequency.

C.1 Fixed Area Plots

A fixed area plot has a specified area and shape, e.g., a circular 0.1 ha plot, within which measurements of the variables of interest are made upon all trees in the population of interest. Fixed area plots have been in use in timber inventories in Europe since at least the 19th Century (Husch *et al.* 1972). The efficient size and shape of fixed area plots depend upon factors such as the characteristics of the population of interest, the types of variables being measured and the costs of plot establishment. For example, large plots tend to be better in forests of variable composition, such as tropical moist forests and may also be considered more desirable than several smaller plots for inventories in remote areas where limiting travel time is a priority (Husch *et al.* 1972). Often, *biareal* or *triareal* fixed plots are employed in timber inventories, where two-size or three-size concentric plots are established respectively, to measure different forest attributes. For example, in Queensland DPI Forestry uses a 0.5 ha circular plot for assessing the stand for current timber volume estimation and a concentric 0.1 ha circular plot for assessing forest regeneration (Cant 1997). That is, a larger plot for the larger trees and a smaller plot for the smaller trees. This recognises the fact that in the natural forests of Queensland (and many other regions), there tends to be more small trees than large trees in any given area and, therefore, provides efficiencies in sampling.

C.2 Variable Area Plots - Point-sampling

Pioneer work on probability proportional to size (p.p.s.) sampling was conducted by Hanson and Hurwitz (1943, cited in Husch *et al.* 1972) and introduced to forestry in the form of *point-sampling* (also called angle count cruising, angle count sampling, angle gauge sampling, prism cruising, plotless cruising, variable radius plot sampling or variable plot sampling) by the Austrian forester, Walter Bitterlich (1947, cited in Shiver and Borders 1996). This variable area sampling technique extends the theory of concentric plots by specifying a different plot size for each and every possible tree diameter at breast height (DBH) (Eyre *et al.* 2000). Larger tree sizes have larger plot areas and smaller tree sizes have smaller plot areas, *i.e.* the probability of sampling any tree is in proportion to its size. When the parameter of interest is related to tree size, for example, timber volume, this is a more efficient sampling method than sampling in proportion to frequency (as in fixed area plots) (Eyre *et al.* 2000; Goulding and Lawrence c1991).

Point-sampling requires an instrument that allows the observer to project a constant angle from a point into the surrounding forest. The observer conducts a *sweep* of the forest (rotates 360 degrees about the angle projection point) siting to each tree within viewing distance at breast height (1.3 m above the ground in Australia). The separation distance between the sides of the projected angle is equivalent to the minimum diameter of any tree to be measured, which increases with distance from the observation point. It follows that inclusion of a tree in the sample depends on its size, distance from the angle projection point, and the size of the projected angle. As illustrated in Figure C.1, when a particular tree is larger than the projected angle, it is an *in* tree and selected in the sample. If the tree is smaller, it is an *out* tree and not selected in the sample. In situations where the tree appears to be the same size as the separation distance of the projected angle, it is a *borderline* tree. The tree can be correctly determined as *in* or *out* by measuring the distance from the angle projection point to the tree and the tree's dbh, and using the following formula (Wood *et al.* 1999):

$$LD = \frac{dbh}{2\sqrt{BAF}}$$

where LD = limiting distance (m)

dbh = diameter at breast height over bark (cm)

BAF = *Basal Area Factor* of the angle projection instrument (defined below)
used in the inventory (m^2/ha)

The limiting distance is the distance from the angle projection point at which a tree of a given dbh is exactly borderline. If the limiting distance is less than the measured distance to the tree, then the tree is *out*, otherwise the tree is *in* the sample.

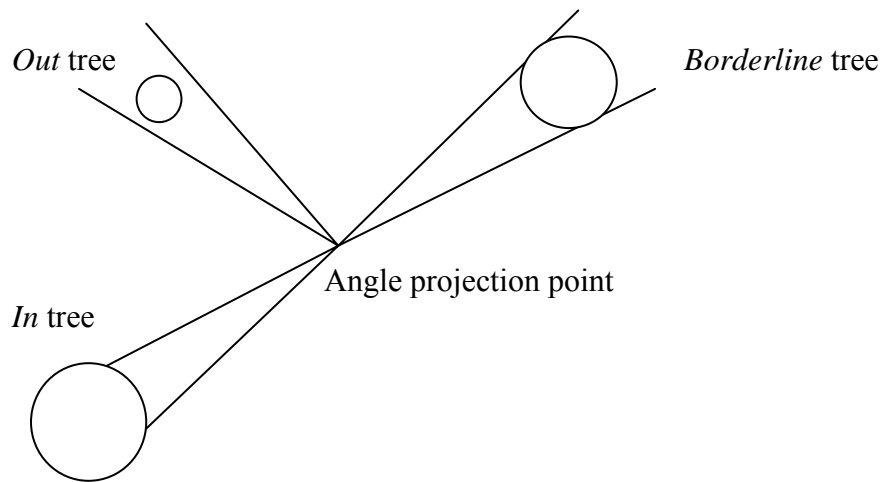


Figure C.1. Possibilities for the relationship of a projected angle to tree dbh in point-sampling

Source: Shiver and Borders (1996).

The *Basal Area Factor* (BAF) is a measure of the angle being projected into the forest and can be calculated according to the following formula (Wood *et al.* 1999):

$$BAF = 2500 \left(\frac{d}{LD} \right)^2$$

where d = diameter of a tree at breast height (m) and other variables are as previously defined

The larger the BAF of the angle projection instrument, the larger the angle being projected into the forest and, consequently, the fewer sample trees that will be selected.

The BAF stipulates the *basal area*¹ per hectare that each sample (*in*) tree represents, regardless of the DBH of the tree. Therefore, a count of *in* trees multiplied by the BAF gives a fast and precise measure of basal area of the stand². This is a useful feature of point-sampling, because there is a strong relationship between basal area and stand timber volume.

Selection of a Basal Area Factor for Point-sampling

The choice of basal area factor (BAF) in point-sampling is analogous to the choice of plot size in fixed-radius plot sampling, since the number of trees included in the sample at each sweep point is inversely proportional to the selected BAF. In general, more trees per sweep will lead to greater precision of forest attribute estimates, meaning fewer plots are needed to achieve the desired allowable error. However, a large number of *in* trees increases measurement time with only marginal improvement in precision or, worse, can lead to biased parameter estimates (Eyre *et al.* 2000).

The major consideration when choosing a BAF is the visibility of *in* trees to the observer. Iles and Fall (1988, cited in Shiver and Borders 1996) found that a large source of error in point-sampling was from trees not noticed by the observer. Therefore, they suggested that for dense forests with thick undergrowth, a high BAF is desirable so that all *in* trees can be easily seen, even if this reduces the tree count to between only three and five per sweep. In open forests and woodlands, a lower BAF is likely to be more appropriate; however, this can result in large trees over 30 m from the observer being *in*, thereby increasing the chances of the observer not noticing all *in* trees. This could lead to a serious underestimation of basal area and subsequently stand volume. Illes and Fall (1988, cited in Shiver and Borders 1996) noted that the tendency for observers to miss *in* trees became particularly apparent when the number of sample trees per sweep exceeded about 10. A suitable BAF for a timber inventory can be calculated as follows Wensel *et al.* (1980, cited in Shiver and Borders 1996):

¹ Basal area is the sum of cross sectional areas of tree boles at breast height and expressed in square metres per hectare.

² For example, if the use of a 2 BAF angle projection instrument resulted in a count of 7 *in* trees, the estimated basal area is 14 m²/ha.

$$BAF = \frac{\text{Estimated stand basal area per hectare}}{\text{Desired tree count per point-sample}}$$

The estimated stand basal area per hectare can be estimated subjectively by a trained eye from field observations or can be determined from the results of a preliminary timber inventory. Where information is available about the stand basal areas of different forest strata, it can be efficient to employ different BAFs within each forest stratum. Even when the estimated stand basal area per hectare is accurate, the desired tree count will only be obtained on average during the inventory. Sometimes many more or far fewer trees will be included in a point-sample. It is poor practice to vary the BAF between sweeps within the same forest stratum to ensure the desired tree count is always obtained (Shiver and Borders 1996). Iles and Wilson (1988, cited in Shiver and Borders 1996) explained that applying this ‘constant tally rule’ will positively bias the results.

Number and layout of point-sweeps within a point-sampling plot

In point-sampling, a plot comprises several point-sweeps, the optimum number being a function of the trade-off between the reduction in sampling error and the marginal cost attributable to additional point sweeps. DPI Forestry recommended between six and 10 sweeps per plot (Cant 1997); however, simulation studies by Denham *et al.* (2000, cited in Eyre *et al.* 2000) indicated that sampling error decreased markedly as the number of sweeps per plot increased from one to four, but then only marginally improved after five sweeps. On this basis, Eyre *et al.* (2000) recommended five point sweeps per plot for forest inventory in Queensland.

Another important consideration in point-sampling timber inventory design is the layout of point-sweeps within the plot. It has been common practice in Queensland to use layouts that ensure that the inventory team are never far from their vehicle (Mannes 2001). While this may be suitable for some forest types, it could be undesirable if there exists a gradient in the characteristic of interest within a stratum. For example, suppose standing timber volume increases with distance from roads, perhaps due to the placement of roads in the landscape or previous harvesting in stands adjacent to roads. Then, as illustrated in Figure C.2, a line transect is likely to provide a more accurate

estimate of timber volume than a diamond plot, which will underestimate standing timber volume in the forest.

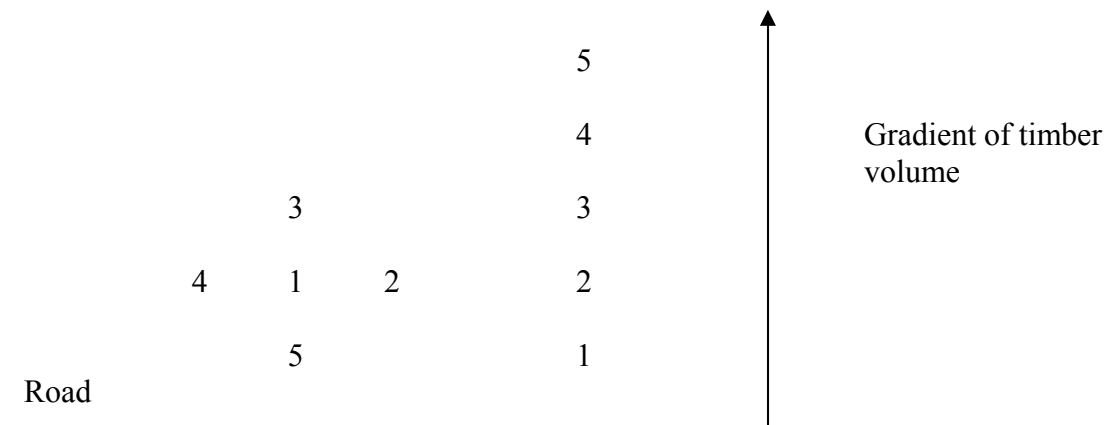


Figure C.2. Five point sweeps arranged in a diamond plot layout and a line transect in a forest where timber volume increases with distance from the road

Statistically, each point within a forest qualifies as an independent sample point for point-sampling. In practice, though, it is prudent to avoid a framework of point-samples that share many common trees, as when points are only separated by a few metres. In Queensland, 50 m appears to be the standard distance between point-samples (Cant 1997; Eyre *et al.* 2000); however it is possible to ensure no overlap by setting the distance between points equal to double the *limiting distance* of the largest trees likely to be encountered (Wood *et al.* 1999). The limiting distance in point-sampling can be estimated as follows (after Shiver and Borders 1996)

$$LD = \frac{dbh}{2\sqrt{BAF}}$$

where LD = limiting distance (m)

dbh = diameter at breast height over bark of the largest trees (cm)

BAF = basal area factor to be used in the inventory (m^2/ha)

C.3 Comparison of Fixed and Variable Area Plot Sampling for Timber Inventory

Point-sampling potentially provides substantial saving of field time over fixed area plots, because the boundaries of fixed area plots do not have to be established. Point-sampling is efficient for timber inventories, because the method favours sampling of the larger trees (of more interest for timber production). However, point-sampling can be difficult in dense stands where the view to trees is impeded (Wood *et al.* 1999). Except in the case of small fixed area plots, point-samples will usually have a greater variance between sampling units, because fewer trees are measured (Shiver and Borders 1996). Consequently, in any comparison of the methods with equal sample sizes fixed area plots will be preferred, but the most suitable comparison is of relative costs in conducting the inventory to achieve the desired allowable error.

Whyte and Tennent (1975, cited in Schreuder *et al.* 1993) and Schreuder *et al.* (1987a, cited in Schreuder *et al.* 1993) concluded point-sampling is more efficient for estimating stand basal area than fixed area plots. Oderwald (1981, cited in Schreuder *et al.* 1993) found that fixed area plots more precisely estimated stand basal area in square lattice stands, such as plantations. Schreuder *et al.* (1987a, cited in Schreuder *et al.* 1993) and Schreuder *et al.* (1992a cited in Schreuder *et al.* 1993) concluded that in tropical forest, point-sampling was most efficient at estimating number of trees by diameter class and volume by diameter class respectively. Scott (1990a, cited in Schreuder *et al.* 1993) commented that, generally, attributes more closely associated with the large diameter classes or correlated with current basal area, such as volume, were better estimated with point-sampling, whereas attributes associated with the small diameter classes, such as mortality and ingrowth, were more efficiently estimated with fixed area plots.

C.4 References

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Appendix D

Preliminary Timber Inventory Methodology

The plots in the preliminary timber inventory were sited subjectively within forest type 1 (see section 9.3 for a description of this forest type). The general location of each plot was described and the main species present in the upper, middle and lower vegetation strata recorded. Notes about the soil, disturbance history, land form, slope position and other general comments were also made. Following the recommendation of Eyre *et al.* (2000), each intensive survey plot consisted of five point-sampling sweeps (see Appendix B for details on this method) arranged in each of the four corners and the centre of a square with a side length of 50 m. A compass bearing at a right angle to the road was set and the first point-sampling projection point location established at approximately 100 m (paced) from the road. This was the far right corner of the plot. With the aid of a compass, the next three point-sampling projection points were established at the remaining three corners of the square. The fifth projection point was established in the centre of the square and a GPS reading of eastings and northings taken. No projection point was established closer to the road than 50 m.

Experience from earlier surveys with the Wik Rangers indicated that a projection angle equivalent to a basal area factor of 1 m²/ha was appropriate for Darwin stringybark forests. All *in* trees (whether alive or dead, and regardless of species and size) were identified by species (wherever possible), had their DBH measured with a diameter tape, and had their total and merchantable height measured with a clinometer. Merchantable height was estimated on all trees to crown break (position of the first major crown shaping branches). Lengths of bole sections below crown break that were considered to be too defective for sawmilling were estimated with the clinometer. All *in* trees were allocated to one of seven growth stages and one of eight tree development constraint categories developed by Eyre *et al.* (2000) for eucalypts. Each tree was then assessed for merchantability and placed into one of three categories: sawlog; potential sawlog - other uses possible; and useless or wood fibre only. Finally, general notes about each tree were recorded, including presence of termite pipes, fire scars and hollows in tree limbs.

The results of the preliminary timber inventory suggested that forest type 1 has a mean basal area of 10.2 m²/ha with a standard deviation of 1.6 m²/ha. The average canopy height is 22 m, although individual *E. tetradonta* trees commonly stand taller than 30 m, with the tallest recorded at 41 m. There are few trees of any species with a dbh greater than 70 cm and the largest diameter recorded was 90.7 cm for an over-mature Darwin stringybark tree.

Timber volume is the stand parameter of most interest from the preliminary inventory, as it can be used to estimate the required number of sample plots necessary to achieve a particular target level of precision in the major inventory. At the time of the preliminary inventory, no tree volume functions had been developed for the major species of commercial interest on CYP. In these circumstances, foresters generally select a geometric solid that approximates tree form to estimate timber volume. The cone is a commonly employed geometric solid and has been used here to estimate biological volume (the volume of the stem with branches trimmed at the junction with the stem) from the preliminary inventory data by assuming tree DBH is the cone's basal diameter and the height of the cone corresponds with total tree height. Biological volume estimates per hectare for trees with a DBH greater than 40 cm are reported in Table D.1 and have been used to estimate the desired number of plots for the timber inventory to achieve a specific level of precision in Chapter 10.

Table D.1. Preliminary inventory estimates of biological volume per hectare of trees with DBH \geq 40 cm in forest type 1

Plot number	Biological volume by species (m ³ /ha)			Total volume (m ³ /ha)
	Darwin stringybark	Melville Island bloodwood	Cooktown ironwood	
1	24.6	6.9	0	31.5
2	10.4	1.5	2.5	14.4
3	17.3	0	5.2	22.5
4	34.5	1.8	0	36.3
Mean	21.7	2.6	1.9	26.2

References

Eyre, T.J., Jermyn, D. and Kelly, A.L. (2000), *Forest Condition and Habitat Assessment in Queensland*, Standards for Forest Assessment Technical Report 02/00, Forest Ecosystem Research and Assessment, Department of Natural Resources, Brisbane.

Appendix E

Assessing the Timber Quality of Trees in the Darwin Stringybark Forests of Aurukun

The physical measurement of diameters and heights of sample trees is a relatively simple task. When appropriate tree volume or taper equations are available, it is then a straight-forward process to generate estimates of gross timber volume. However, as a natural fibre exposed to natural processes in a forest (e.g., fire and disease), wood is susceptible to damage that can reduce the potential range of end-uses for which it is suitable. To obtain timber volumes by quality, the additional quality variable must be recorded in the field during the timber inventory. Assessment of timber quality, particularly on a standing tree (as in a timber inventory) is a difficult task because many of the variables that affect timber quality can rarely be observed. For example, some characteristics of trees that affect wood quality include tree size, tree form, branch knots, wood density, compression wood, spiral grain, wood stain, decay and termite damage. Except for tree size and, to a lesser extent, tree form, the impact of other variables on wood quality are often difficult to assess on a standing tree. However, if these characteristics of the timber are not accounted for, a large overestimation of merchantable volume may result.

E.1 Training for Timber Quality Assessment in the Darwin Stringybark Forests of Aurukun

Timber quality assessors are skilled professionals. As an inexperienced timber quality assessor, the author required training before he could confidently assign trees to timber quality classes. Throughout four weeks of fieldwork in 2000 with the Wik timber crew and Wik rangers, I learned valuable skills in identifying trees with termite pipe defect. This included judgement based on external characteristics of trees and the sound ('ring') of the tree when hit with an axe. During August 2001, the author organised a two-week field trip in Darwin stringybark forest type 1 in Aurukun Shire with three DPI Forestry inventory and tree marking officers. The main objective of this trip was to destructively sample *E. tetradonta* trees for development of the stem taper and volume functions

discussed in Chapter 9; however, the author also received training from DPI Forestry officers in assessing log quality on standing trees. The author had the opportunity to practice assessing the quality of log sections on standing trees and then to check how close his assessment was after it had been cut down for measurement for development of the taper function.

E.2 Methods Adopted for Assessing the Timber Quality of Sample Trees in Aurukun

A log quality classification system was developed before undertaking the timber inventory. Given the author's inexperience in log quality classification, the number of log quality classes were kept to a minimum. Four classes, termed A log, B log, R log; and U log, were defined. They are loosely based on DPI Forestry's compulsory sawlog, optional sawlog, roundwood and useless product types respectively (Department of Primary Industries Forest Service 1994; Department of Primary Industries Forestry 1999). The characteristics used to assign each log section of standing sample trees to a log quality class are summarised in Table E.1 and described in detail below. If a log section did not exhibit all the characteristics of an A log, then it was assessed against the characteristics of a B log and so on, until the log could be assigned to an appropriate quality class. The useless log class is a catch-all for logs too defective to be classified as a R log.

Accounting for termite pipe defect is the single most difficult aspect of timber quality assessment in the study region. It is common for termite pipes to extend inside the heartwood of trees from the ground, up, and from the crown, down (termites can construct mud tunnels on the bark of Darwin stringybark trees from the ground into the tree crown to exploit weaknesses in the tree crown). However, the entire bole is not always affected, so it is possible for defect free timber to be cut from above or below the activity of termites. Determining if and where the termite pipe ends and a higher quality log section begins is difficult and requires much log grading experience.

Table E.1. Characteristics used to assign each log section of standing sample trees to a log quality class

Log characteristic	Log class		
	A	B	R
Max. termite pipe size (% of bole cross section affected)	50 20 (requirement of poles)	65 50	75
Max. bend within a log (degrees)	5	10	15
No. limbs (max. % of bole cross section affected in parentheses)	1 (25)	2 (50)	Unlimited (75)
Irregular shape	No	Permitted	Permitted
Spiral grain	No	Permitted	Permitted
Fungal defect and burls (max. % of bole cross section affected in parentheses)	No	No	Permitted (50)
Fire or physical damage (max. % of bole circumference affected in parentheses)	No	Bark (25)	Wood (50)

Notes: Direct measurement of termite pipe size and percentage of bole cross section affected by defect from the presence of limbs cannot be accurately determined without destructive sampling. The extent of these defects had to be estimated subjectively.

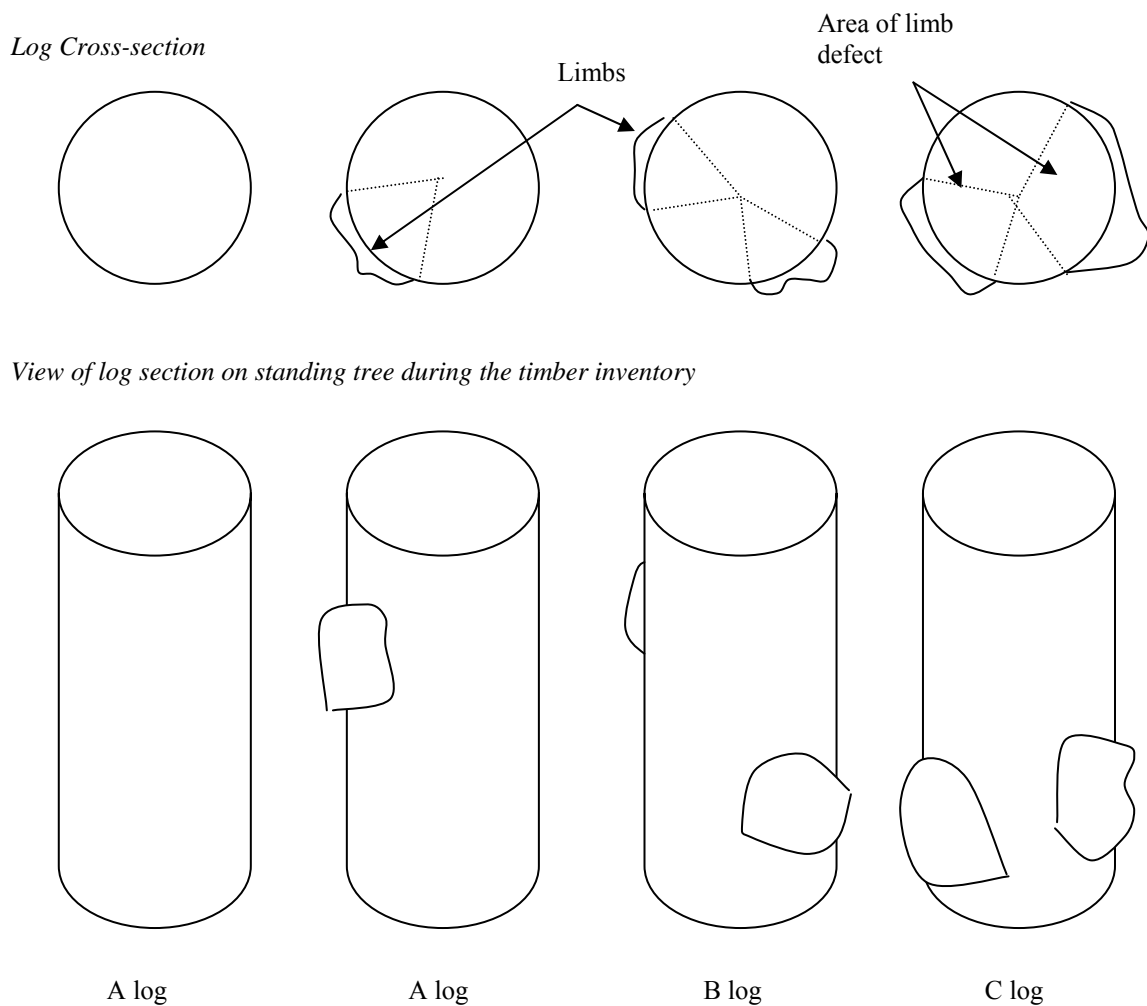
Direct measurement of termite pipes is possible only by felling or auguring sample trees. Both methods were considered too expensive and time consuming to include as part of this timber inventory. Therefore, indirect assessments of pipe sizes were made. Firstly, the sample tree bole was examined for bumps - termite breather holes. The experience of the Wik Timber Crew and Rangers is that log sections with numerous bumps have a large termite pipe and are generally useless for sawn timber production. This was confirmed by a small number of trees with bumps destructively sampled with the assistance of the Wik Timber Crew and DPI Forestry during development of the taper and volume functions for Darwin stringybark. Sample tree crowns were also examined for hollows where major limbs had broken off, as this can indicate the presence of a pipe in the upper part of the tree bole. Finally, sample tree boles were hit with an axe and the 'ring' of the tree used to judge the presence and size of a pipe. If the ring of the tree was relatively high pitched, sharp and clear, then the tree is likely to have no more than a small pipe, if it has one at all. This was the requirement for an A log. Under DPI Forestry's current log quality assessment guidelines (Department of Primary Industries Forest Service 1994), log sections of between 35 cm and 100 cm centre diameter under bark can have pipe defect up to of about 50% of centre diameter

and still be classed as ‘compulsory sawlog’. A relatively lower pitched ring that is less sharp is likely to indicate a larger pipe, and a B quality log. The signature of a large pipe is a low pitch ring or ‘boom’ with an echo. At best, such a log section could be classified as a R log. In extremely hollow trees, the tree bole can be felt to move with the impact of the axe. Sometimes pieces of the mud structures of the termite nest can be heard falling inside the tree. These log sections have been categorised as useless (U).

The assessment of each log section for bend was subjective. No measurements were made and the permitted bend angles in Table E.1 are approximate only. For log sections with a centre diameter greater than 40 cm, logs could be classified A when they were straight or had a slight bend up to about five degrees. B logs were allowed a bend up to about 10 degrees and R logs up to about 15 degrees. Smaller logs, with a centre diameter less than 40 cm, were classed A only when completely straight. A five degree bend was permissible on B logs less than 40 cm centre diameter and a 10 degree bend on R logs.

Since log quality assessment ceased at crown break, and because of the branch shedding nature of eucalypts, few branches were expected within the log sections being assessed for timber quality. Infrequently, however, eucalypts will retain large lower limbs well below the level of the general canopy. To be classified an A log, the log section could include a maximum of one limb and this limb could not be judged to affect more than 25% of the log cross-sectional area. B logs were permitted up to two limbs, provided they were judged to affect less than 50% of the log cross-sectional area. Where greater than 50% of the cross-sectional area was likely to be affected, the highest classification the log could receive was R. Any number of limbs were permitted on R logs; however, no more than 75% of the log cross-sectional area could be affected by branch defect. If there were two or more limbs on a tree at the same height, then the tree bole would be sectioned at a point below the limbs and the next log section would begin above the limb defect. The log quality classifications according to limb defect are illustrated in Figure E.1.

Figure E.1. Log quality classifications according to limb defect



Tree boles sometimes include sections that are irregular in shape, for example, fluting or sharp taper of the bole near the ground (butt swell). A logs were not permitted to have irregular shape. Irregular bole shape is uncommon in the timber species of interest in the study area.

Trees with bark that appeared to be twisting around the tree were judged to have spiral grain. Logs from these trees could not be assigned an A quality.

Large fungal infections or burls are common in Darwin stringybark boles, although they are infrequent in Melville Island bloodwood and Cooktown ironwood stems. Logs of quality A and B were not permitted to include any fungal defect. If less than 50% of the circumference of a log with a centre diameter of 40 cm or more was affected, the

infected section could be included as part of a R log. In reality, however, when fungal infections are visible on trees in Darwin stringybark forests, they almost always occupy the entire circumference of the tree at that point. In these cases, the tree bole would be sectioned above and below the infection and the burl was assigned a useless log classification.

Fire damage, called a fire scar, is common on trees in the study region. Other physical damage can be caused, for example, by falling limbs and adjacent trees. For the purposes of this inventory, fire or physical damage was recognised when the bark had been killed over a portion of a log section exposing the underlying wood. Logs could only be given an A classification if no visible wound has penetrated the bark. B logs were permitted damage that had removed bark from up to 25% of the log circumference, so long as the exposed wood was solid. If the exposed wood showed signs of weakness, then the log section could be classified R (or useless if damage was severe). Log sections with bark removed from more than 25%, but less than 50% of the log circumference, could be classified R (or useless if damage was severe). Where bark had been killed over 50% of the circumference of the log section, the log was classified useless. All log sections less than 30 cm centre diameter with fire damage that had killed any proportion of the bark were classified useless.

E.3 References

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Appendix F

Field Measurement Methods for the Timber Inventory in Aurukun

In this Appendix, the equipment employed while conducting the timber inventory are listed, sample tree measurement methods described, and the growth stage classification for individual trees explained.

F.1 Equipment for Timber Inventory in Aurukun

Plot location

- Global positioning system (GPS)
- Maps of the study area
- compass
- Hip chain

Sweep equipment

- Husky data storage device (Husky)
- Forestor Vertex
- Relascope
- 50 m steel tape
- 1 m steel diameter tape
- galvanised nails and aluminium tags
- axe
- clipboard, data sheets, pencils
- 1 BAF optical wedge

Other equipment

- satellite phone
- chainsaw
- first aid kit

F.2 Measurement of Sample Trees During Point-sampling in Aurukun

The inventory team consisted of two people; a paid forestry graduate assistant and the author, fulfilling the roles of the *sweeper* and the *walker* respectively. The sweeper's role was to identify the *in* trees by performing a basal sweep with the wedge prism and to record the measurements made by the walker. The walker's role was to walk to each *in* tree to measure its height and diameter and assess its timber merchantability.

The plot was located by the inventory team after entering the eastings and northings from the *plot location sheet* (described in Chapter 10) into the GPS. This point was approached as close as possible in the vehicle without leaving the road³. The position of the vehicle then became the starting point for the plot transect. The plot location sheet detailed whether the plot would be established on the left or right hand side of the road. The Forestor Vertex was calibrated (and recalibrated when the air temperature changed by five degrees or more) and the compass was used to determine a plot transect bearing perpendicular to the road. With the loose end of the hip chain tied to a suitable anchor point by the side of the road, the inventory team walked in 100 m from the roadside at the prescribed bearing to establish the first point-sample⁴.

The eastings and northings of the first point-sample were obtained with the GPS and entered into the Husky. Beginning in the direction of magnetic north and rotating to the right, the *sweeper* performed a sweep of the stand with the optical wedge (as described under point-sampling in Appendix B). The first *in* tree had a galvanised nail with an aluminium tag nailed into the stump within 10 cm of the ground on the side of the tree nearest the *sweeper*. This was to aid point-sample relocation in the future. Marking the first tree of the sweep will facilitate re-measurement in the future, allowing individual trees to be identified and tree growth estimated for the intervening period. Where the *sweeper* identified a tree as being *borderline*, the *walker* measured the DBH of the tree with the diameter tape and the distance from the tree to the sample point with the

³ Since plots were located along roads at a scale of 1:250,000 and because the mapped location of some roads was inaccurate, the actual location of the plot was sometimes several hundred metres off the road.

⁴ The only exception to the described placement of the first plot was in forest type 5. This stratum is confined to within 50 m of particular roads, so the first point sweep was conducted only 25 m in from the road. Subsequent point sweeps were established parallel to the road at 100 m spacing.

Forestor Vertex. These measurements were entered into the Husky, which has a module to check whether a tree is *in* or *out* of the sweep.

Once a tree had been determined as *in*, the *walker* measured its DBH with the diameter tape to the nearest 0.1 cm rounded down. In Australia, breast height is 1.3 m above ground level and breast height was marked on the *walker's* clothing prior to commencement of the day's work. Wood *et al.* (1999) reported the standard techniques for measuring DBH on forked, leaning, damaged and deformed trees, which were employed in the major timber inventory. Next, the entire tree bole to crown break was assessed for its potential to produce logs of the various log classes described in Appendix D. The *walker* then moved away from the tree a suitable distance (about 20 m) to measure to the nearest tenth of a metre the heights at which log quality changed, crown break height, and total tree height with the Forestor Vertex. Log classes were assigned to each log section that could be cut from the tree. Finally, the small-end diameter over bark at crown break was estimated with the Relascope and the tree was allocated to a growth stage category (method detailed in the following section). As each measure and assessment was made, the *walker* called them out to the *sweeper* who entered them into the Husky. The *walker* then moved on to the next *in* tree where this procedure was repeated.

When all *in* trees at the first point-sample had been measured, the inventory team proceeded along the same compass bearing from the road another 100 m measured by the hip chain. The bearing and distance were recorded in the Husky. The second and successive point-samples of the plot were conducted as the first, except that eastings and northings of the point were not recorded. The plot was completed when five sweeps had been performed. The inventory team then returned to the vehicle and drove to the location of the next plot.

F.3 Treatment of Non-Representative Sample Sites

Errors in vegetation and other maps of the study area can result in some inventory plots being placed outside the target stratum. Some plots may fall on roads, in waterholes, in small patches of a different forest type or in gaps in the stand where there are no trees. It is tempting to move these plots into more *representative* parts of the forest; however, if

these areas are counted as part of the forest stratum when sample estimates are aggregated to the whole forest, whether intentionally or because finer stratification of the forest is not possible, then plots falling in *non-representative* areas should be conducted⁵. Not doing so will result in overestimates of stratum totals and underestimates of associated standard errors of basal area, timber volume and other characteristics of interest (Shiver and Borders 1996). In this study, plots were inspected as close as practical to the site selected in the office.

F.4 Growth Stage Classification of Trees in Aurukun

Classifying individual trees to reflect their position within the structure of the forest can be used for purposes such as evaluating and describing the forest's productive condition and aiding implementation of harvest plans (Florence 1996). Although the classification is subjective, assignment of trees into growth stages would be beneficial for defining and simulating forest management strategies in Aurukun. For example, a prevalence of old trees in a stand is likely to be indicative of a forest that is past its timber production peak, although it may have high conservation value and be important for hollow dependant fauna. A stand with a spread of older and younger trees may indicate a pool of advance growth capable of responding to release if the older stems are harvested. A stand with a high proportion of younger trees may indicate a vigorous forest that could be managed to maximise future timber production. This is information that cannot be gleaned from measures of height and diameter alone. Assignment of trees into development constraint classes could also be useful for this purpose.

DNR reviewed several growth stage classifications that have been developed for Australian eucalypt forests and from these developed their own classification suitable for Queensland, including the State's drier forests (Eyre *et al.* 2000). DNR's classification of eucalypts into seven growth stages is an attempt to standardise field data collection in Queensland. The usual progression of a eucalypt from seedling to death is described by six stages (Eyre *et al.* 2000): regeneration, development, consolidation, fully developed, deteriorating and senescent. The seventh growth stage, indeterminate, is a 'pseudo stage' where none of the above stages are pertinent. This is

⁵ For example, a point-sampling plot situated in a lagoon is recorded as having zero trees in the sweep, no measurements are made and the field crew moves onto the next plot location.

often the result of some damage or set back, *e.g.* from a severe fire. This indeterminate classification is also used where a tree that is not overmature is almost dead. Figure F.1 illustrates the growth stage classification. A copy of this classification was on hand in the field at all times.

The terminology of Eyre *et al.* (2000) was found to confuse forestry professionals in Queensland. Foresters are more familiar with the terms: seedling, pole, early mature (spar), mature, overmature, and senescent (Florence 1996), which are analogous to the six stages of Eyre *et al.* (2000).

F.5 References

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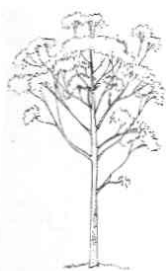





<p>Regeneration stage (R)</p>  <ul style="list-style-type: none"> • The tree is very small • The tree is in a consolidation phase prior to initial height increase and entry into the canopy system. 	<p>Development stage (Y)</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;">  </div> <div> <ul style="list-style-type: none"> • The tree has a well developed stem with a crown of small branches but below maximum height for the stand condition. </div> <div style="text-align: center;">  </div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 48%;"> <p>If a vigorous tree:</p> <ul style="list-style-type: none"> • There is an apically dominant (rounded or pointed) crown with the majority of branches lying at an acute angle to the main stem • Height is increasing • Semi-permanent branches grow like modified saplings from the main stem </div> <div style="width: 48%;"> <p>If a non-vigorous tree:</p> <ul style="list-style-type: none"> • Crown may not be apically dominant but there is an absence of forming branches • There is potential for further height development if vigour returns </div> </div>	
<p>Consolidation stage (E)</p>  <ul style="list-style-type: none"> • Apical dominance has been lost • The tree has developed permanent shaping branches • There is still potential for further development of the crown • Tree is approaching maximum height 	<p>Fully developed stage (M)</p>  <ul style="list-style-type: none"> • Crown has reached full lateral development although branch thickening can occur • Overall height and crown spread remains fairly constant as extremities die and are replaced by new crown units • Tree may remain in this stage for a long time 	<p>Deteriorating stage (L)</p>  <ul style="list-style-type: none"> • The crown, although remaining healthy, shows evidence of contraction due to increasing depth of lower order branches • Distorted branches and burls start to appear
<p>Senescent stage (O)</p>  <ul style="list-style-type: none"> • Increased death of major branches and development of a 'stag headed' crown • Decrease in crown diameter • Decrease in crown leaf area • Distorted branches and burls common 	<p>Indeterminate (I)</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;">  </div> <div> <p>Intermediate stage is used when the tree does not comply with any of the previous growth stages. This may be the result of some damage or setback.</p> <p>"I" is used where:</p> <ul style="list-style-type: none"> • More than one stage is apparent on the one tree eg coppice or advanced growth on an old root stock </div> <div style="text-align: center;">  </div> </div> <ul style="list-style-type: none"> • A catastrophe has removed all or most of a crown but coppice shoots are appearing • A tree which prior to the damage was not overmature but is now almost dead • The observer is unsure of the significance of damage to the tree and is unable to confidently class the tree into one of the preceding stages 	

Figure F.1. Growth stage classification of trees in Aurukun